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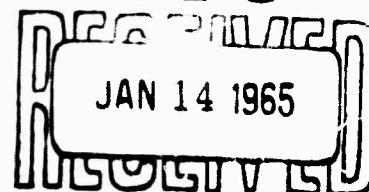
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Director of Aeronautical Sciences  
Air Force Office of Scientific Research  
Washington 25, D. C.

Attention: SRHP

Contract No.: AF 49(638)-565  
Project No.: 4759  
ARPA Order No.: 24-61, Task 2  
Contractor: Stanford Research Institute ✓

Subject: Study of Origin and Propagation of Disturbances  
in the Burning of Solid Propellants (SRI Project PRU-2770)  
Narrative Progress Report, No. 12; ✓  
October 1-December 31, 1961

Instrumentation

The pulse tube currently in use is made of cylindrical 1-1/2 inch I. D., 2-inch O. D. steel tubing in place of the rectangular aluminum tubing used previously. The new tubing is rigid, requires no special measures to eliminate wall vibrations, and is far more convenient from a design standpoint. At present pulse levels (from about .002 to .02 atm peak overpressure) we are using a somewhat more sensitive microphone button (47 db below 1 v/dyne) than previously (80 db below 1 v/dyne); electrical noise has been effectively eliminated. A new energy storage unit for the pulse source has been built; after some slight modifications, it will have a continuously variable stored energy from 1 joule (0.5  $\mu$ f at 2 kv) to 100 joules (4  $\mu$ f at 5 kv).

The electronic system for displaying the incident and reflected pulses in two separate sweeps of the oscilloscope has been completed. A typical record is shown in Fig. 1. The traces may be displayed either continuously, or as a series of dots at 10, 20, 30, 40, or 50  $\mu$ sec intervals. The brightening of every tenth dot is optional. The vertical offset between the two pulses is adjustable.

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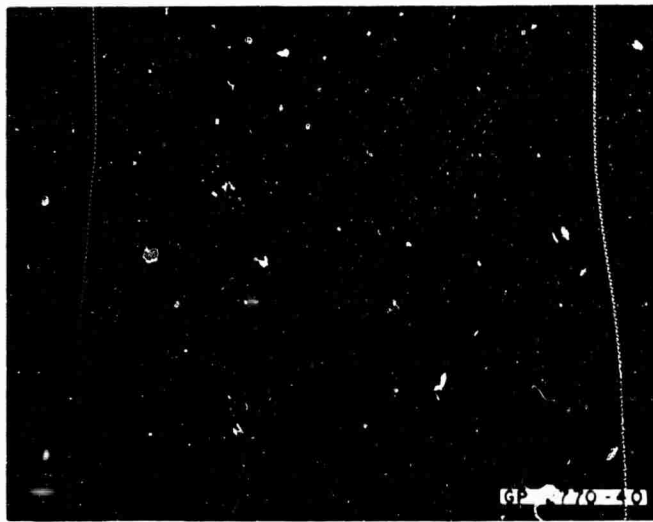


FIG. 1 INCIDENT AND REFLECTED PULSE DISPLAYED  
IN SEPARATE SWEEPS (incident pulse: top) TIME  
BETWEEN ADJACENT DOTS: 20  $\mu$ sec. EVERY  
TENTH DOT BRIGHTENED

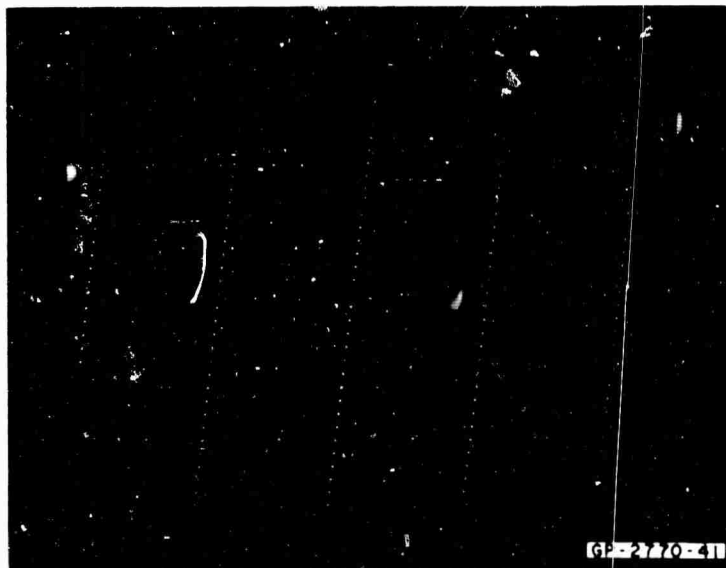


FIG. 2 CALIBRATION RECORD TO CORRECT FOR ANY  
NONLINEARITY IN VERTICAL DEFLECTION.  
ADJACENT DOTS ON DIAGONAL LINES ARE  
SEPARATED BY CONSTANT VOLTAGE  
INCREMENTS

Figure 2, a calibration record, shows a continuous sawtooth waveform at constant time intervals. The central portion of the up-sweep is extremely linear; the vertical distance between any two adjacent dots represents voltage increments constant to well within 0.5 percent.

The ruled overlays for reading the vertical deflection of the dots are now being checked for accuracy and should be available for use within a week.

### Amplitude Effect

The new recording system permits a rather dramatic demonstration of the relation between peak overpressures and the spreading out of a pulse during propagation. (See Operating Report No. 10.) By using zero offset between the incident and reflected pulses, and by proper adjustment of the delay of the second sweep, it is possible to obtain a picture like Fig. 3, with the peak of the first compression (recorded as a negative deflection) in phase for the two (filtered) pulses. Even at the low peak overpressure of about 2% ambient, the lag of the later maxima and minima of the reflected pulse behind the incident pulse is quite obvious. In Fig. 4, obtained at a peak overpressure of about 0.2% of ambient, all the maxima and minima (so far as they can be resolved) appear to be in phase. It is thus quite likely (see Operating Report No. 10) that the real part of the apparent admittance calculated on the basis of Fig. 3 would have a negative portion at the lower end of the spectrum but would be positive throughout the frequency range of interest in the case of Fig. 4.

### Standard Sample

A standard low-admittance sample has been prepared by cementing grade 50-D garnet sandpaper to an aluminum block. Pulse records have been obtained for this sample and for a plain aluminum block at peak overpressures of .02 and .002 atm. These records will be read and processed as soon as the overlays are available. Since the apparent admittances will be quite different at the two pressure levels, agreement or disagreement of the calculated true admittances should provide an effective test of the theory proposed in II D, Operating Report No. 10.

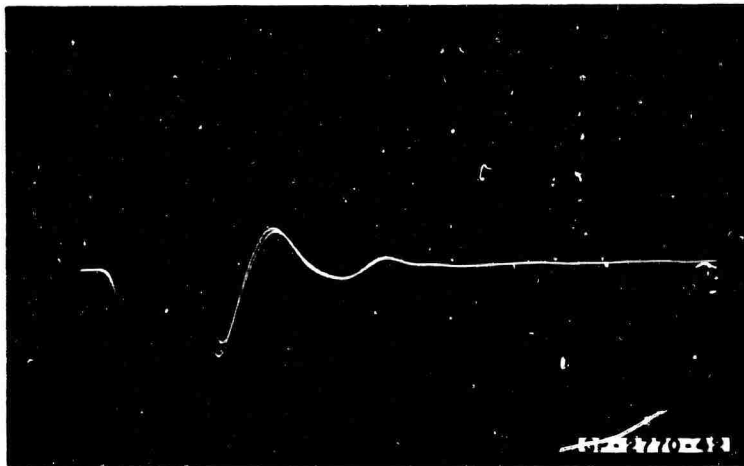


FIG. 3 INCIDENT AND REFLECTED PULSE DISPLAYED APPROXIMATELY IN PHASE. (Termination: Aluminum block.) NOTE THE FREQUENCY SHIFT (Peak over pressure about 0.02 atm.; 3 kc cut-off)



FIG. 4 THE SITUATION OF FIG. 3 BUT AT ONE-TENTH THE PEAK OVER PRESSURE. NOTE THE ABSENCE OF FREQUENCY SHIFT

### Measurements in a Moving Air Stream

We have begun a study of the effects of gas flow in the tube. Air is forced under pressure through a fine, porous brass disc which forms the acoustic termination of the pulse tube. At the present pulse pressures (0.02 atm), the turbulence in the tube at flow rates of 20-40 cfm is too large to permit accurate measurements. However, it appears likely that with a moderate increase in peak overpressure (to about 0.1 atm) this difficulty can be overcome. A qualitative examination of the records obtained thus far does not disclose any significant change in the admittance of the brass disc due to the motion of the air.

### Preparations for Measurements on Burning Surfaces

Two schemes are presently under consideration for the protection of the microphone from the hot combustion products. The first involves passing a current of cold air (or other gas) toward the burning surface and impinging on the stream of hot product gases. The microphone is located in the cold stream, and the impinging gases are allowed to leave the tube through a network of fine holes. Unless the specific acoustic admittance of the cold gas matches fairly closely that of the combustion products, the reflections due to the mismatch at the interface may be too large to allow a proper interpretation of the results. Significant reflections may also arise from the nonplanar structure of the mixing zone. The necessary hardware for experimentally investigating the feasibility of this method is nearing completion.

The second scheme envisages some form of enclosure for the microphone. We have designed a small antechamber to fit over the microphone button whose lowest resonant frequency we hope to be able to keep above several kilocycles. Such a chamber will thermally insulate the microphone proper from the hot gases during the several seconds required for a burning run. Large possible acoustic losses in the antechamber can be compensated by using a more sensitive

microphone. (It may be recalled that the only requirement for the pressure transducer is that its response be linear with amplitude; the frequency response need not be flat.) The chamber is now being built and should be ready for acoustic tests within a few weeks.

Ignition tests have been performed with a specific propellant. The propellant selected for initial study has a polyurethane binder and contains 80% ammonium perchlorate. The density of this material is  $1.66 \text{ gm/cm}^3 (\pm 2\%)$  and the measured burning rate is  $0.1 \text{ cm/sec}$  at atmospheric pressure. A number of calculations have been performed yielding the following information concerning the product gases at atmospheric pressure and adiabatic flame temperature:

1. Composition, moles/100 gm of mixture

HCl	0.6295
N <sub>2</sub>	0.3517
H <sub>2</sub> O	1.5790
H <sub>2</sub>	0.3834
O <sub>2</sub>	0.0054
O	0.0034
OH	0.0368
Cl	0.0516
NO	0.0029
H	0.0446
CO	0.6340
CO <sub>2</sub>	<u>0.3951</u>
Total	4.1174

Essentially absent (0.0000) are  $\text{Cl}_2$ ,  $\text{N}$ ,  $\text{HCN}$ ,  $\text{C}_2\text{H}_2$ ,  $\text{C}_{(\text{Vapor})}$ ,  $\text{C}_{2(\text{Vapor})}$ ,  $\text{CN}$ , and  $\text{CH}_4$ .

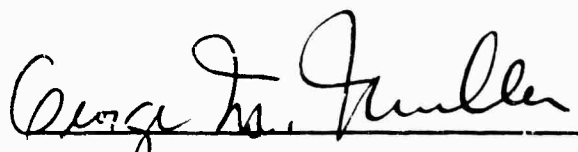
2. Adiabatic flame temperature:  $2581^\circ\text{K}$
3. Ratio of specific heats,  $\gamma$  : 1.224
4. Density,  $\rho$  :  $1.1468 \times 10^{-4} \text{ gm/cm}^3$
5. Sound speed,  $c$  :  $1.101 \times 10^5 \text{ cm/sec}$   
Hence,  $\rho c$  :  $12.626 \text{ gm}/(\text{cm}^2) (\text{sec})$
6. Linear gas velocity (one dimensional flow) =  $140 \text{ cm/sec}$ .

The choice of this propellant is logical because it is a type with which we have had considerable developmental experience. Further advantages in this study are its fairly good ignitability, modest burning rate, and absence of solid and liquid combustion products.

Discs of this propellant (1-1/2 inches in diameter and 1/2 inch thick) were prepared for obtaining preliminary information on ignition and uniformity of burning. The discs were cemented (using flame-resistant potting agent) within short lengths of steel tubing (1-1/2 inch I. D. , 2-inch O. D. ) representing a section of the test shock tube. Various arrangements and igniter compositions were tried, and the following procedure was found to give the most satisfactory ignition: a thin layer (1/16 inch thick) of flash powder is applied to one flat surface of the propellant disc. The flash powder is ignited by a small patch (1/4 inch in diameter) of pyrotechnic close to the periphery of the disc. The pyrotechnic, in turn, is ignited by a bridge wire (Nichrome V, 0.0019 inch diameter) supplied by du Pont. The pyrotechnic is a 50-50 mixture of Heat Powder F-33-B (Catalyst Research Corp. ) and nitrocellulose. It is applied as a slurry in butyl acetate. The layer of flash powder is prepared from a mixture of potassium perchlorate (68%), magnesium powder (30%), and boron powder (2%). This powder mixture is made into a slurry by combination with acetone and nitrocellulose (0.1 gm) which is poured on the propellant surface. On drying an adherent crust forms.

A notion of the uniformity of ignition and burning was obtained from motion pictures of the emergence of flame at the bottom surface. The pictures suggest that after burning for about 12 seconds there are no steep bumps in the burning surface. Instead there are gradual changes in depth resulting in over-all differences up to 1.5 mm. It is proposed to evaluate the effect of surface nonuniformities of this order on acoustic admittance measurements before deciding whether the ignition procedure or burning characteristics require improvement.

  
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PRU-2770

Approved:

  
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